



UNITED STATES DEPARTMENT OF COMMERCE
National Telecommunications and
Information Administration
Washington, D.C. 20230

February 26, 2004

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
445 Twelfth Street, S.W.
Washington, DC 20554

RE: *Wireless Telecommunications Bureau Seeks Comment on MariTEL, Inc. Petition for Declaratory Ruling and National Telecommunications and Information Administration Petition for Rulemaking Regarding Use of Maritime VHF Channels 87B and 88B, DA 03-3585, RM-10821*

Dear Ms. Dortch:

Enclosed please find an original and two (2) copies of an ex parte letter in the above-referenced proceeding from Fredrick R. Wentland, Associate Administrator, Office of Spectrum Management, National Telecommunications and Information Administration, to John B. Muleta, Chief, Wireless Telecommunications Bureau, Federal Communications Commission, with a copy to Edmond J. Thomas, Chief, Office of Engineering and Technology. Per the public notice, copies were also mailed to Qualex International; Maria Ringold of the Consumer and Governmental Affairs Bureau, Reference Information Center; and Tim Maguire and Jeffrey Tobias of the Wireless Telecommunications Bureau, Public Safety Wireless Division.

Please direct any questions you may have to the undersigned.

Respectfully submitted,

Kathy Smith
Chief Counsel

enclosures

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UNITED STATES DEPARTMENT OF COMMERCE
National Telecommunications and
Information Administration
Washington, D.C. 20230

FEB 26 2004

Mr. John B. Muleta
Chief, Wireless Telecommunications Bureau
Federal Communications Commission
The Portals
445 Twelfth Street, S.W.
Washington, DC 20554

Re: Wireless Telecommunications Bureau Seeks Comment on MariTEL's Inc. Petition for Declaratory Ruling and National Telecommunications and Information Administration Petition for Rulemaking Regarding the Use of Maritime VHF Channels 87B and 88B, DA 03-3585, RM-10821

Dear Mr. Muleta:

The National Telecommunications and Information Administration (NTIA) manages and authorizes the Federal Government's use of radio frequency spectrum. The Federal Communications Commission (FCC) recently issued a Public Notice seeking comments on a petition for declaratory rulemaking submitted by MariTEL, Inc. (MariTEL) and a petition for rulemaking submitted by NTIA.¹ Regarding this Public Notice, NTIA submitted Reply Comments stating that the FCC should deny MariTEL's Petition and should designate Channels 87B and 88B exclusively for the Automatic Identification System (AIS).² NTIA also noted that the Reply Comments would be supplemented with a technical analysis performed by the Joint Spectrum Center (JSC) at the request of the United States Coast Guard (USCG).

In the United States, the 138-174 MHz Band is used extensively because of its desirable propagation characteristics. This band is used for various government and non-government services that include: public safety, utilities, conservation, forestry, highway maintenance, paging, broadcast links, amateurs, business and education, and maritime. These services must address the special problems imposed by the radio frequency (RF) congestion that exists in highly populated areas, including busy ports and waterways.

The VHF maritime radio allocation in the United States operates in two bands (156.025-157.425 MHz and 161.800-162 MHz). At some locations high-level RF transmitters are permitted to operate below, above, and in between these two bands. For example, pagers are authorized to operate in the middle of the band, and the National Oceanic and Atmospheric Administration weather radio service and other Federal government users are permitted to

¹ See Wireless Telecommunications Bureau Seeks Comment on MariTEL, Inc. Petition for Declaratory Ruling and National Telecommunications and Information Administration Petition for Rulemaking Regarding the Use of Maritime VHF Channels 87B and 88B, *Public Notice*, DA 03-3585 (November 7, 2003).

² See Letter to John B. Muleta, Chief Wireless Telecommunications Bureau, Federal Communications Commission, from Fredrick R. Wentland, Associate Administrator, Office of Spectrum Management, NTIA, in DA 03-3585 (December 11, 2003).

operate in the upper part of the band. This situation poses a challenge for those who depend on reliable VHF marine radio communications. This challenge has been recognized for many years by those who use shipborne radios or manage a VHF radio infrastructure. Many times the FCC has been asked to eliminate the RF interference in the VHF marine band in the major port areas. In most cases, the problem was determined to be due to legitimate high-level signals that were not on the marine frequencies of interest but on other frequencies surrounding the marine band. In these cases, the VHF marine radio receivers were found to be incapable of receiving weak desired signal levels in the presence of strong undesired signal levels in this highly congested frequency band.

The Radio Technical Commission for Maritime Services (RTCM) is a non-profit scientific and educational organization, focusing on all aspects of maritime radiocommunications, radionavigation, and related technologies. The RTCM formed a special committee (RTCM SC117) that was comprised of VHF marine radio manufacturers, user groups, and radio communications experts, both government (FCC, NTIA, and USCG) and non-government (radio communications engineers, consultants, and service providers such as MariTEL), to address the problem of the intense electromagnetic environment in the VHF maritime band. The JSC performed field measurements and presented a technical paper to the RTCM General Assembly in May 1996, that specifically addressed this problem (before AIS was being considered). In response, RTCM SC117, with participation from MariTEL, (at the May 1996 Meeting) formed a task group that visited various ports in which marine users had filed complaints of RF interference with the FCC. In all cases, the RF interference was determined to be a receiver mixing product of multiple high-level signals from non-marine users of the VHF band. RTCM SC117 has now published a voluntary standard (RTCM Paper 87-99/SC117-STD, October 10, 1999) for marine radios that significantly improves receiver performance (but does not completely eliminate the interference problems) in this intense electromagnetic environment.

Furthermore, regarding land mobile operations, the Association of Public Safety Communications Officials (APCO) also addressed the congested signal environment issue in APCO 25. The APCO 25 communications protocol employs techniques that have been proven to effectively mitigate interference effects in the Land Mobile Radio Service.³ These techniques include forward error correction (FEC) and interleaving. It is noted that these techniques are used, for similar reasons, in Digital Selective Calling (DSC) for transmitting digital distress calls in the Global Maritime Distress and Safety System (GMDSS) in the maritime environment. Now that these techniques have become common practice in both the land mobile and maritime services, they have been proven to be effective in mitigating the deleterious effects of the radio environment.

The attached JSC Report, EMC Analysis of Universal Automatic Identification and Public Correspondence Systems in the Maritime VHF Band (February 2004), discusses the potential impact of the AIS on PC services. The JSC Report contains a number of simplifying assumptions, including a benign environment,⁴ operational characteristics for the PC,⁵ and no

³ See <http://www.apcointl.org/frequency/project25/information.html#whatis>

⁴ This analysis ignores typical radio noise that normally exists in a marine environment.

⁵ There are currently no wide-coverage-area PC systems operating in the band. MariTEL terminated their operations on June 6, 2003.

effects from multi-path fading. As a result, the JSC Report provides a limited analysis of AIS effects on MariTEL's operation. Nevertheless, the JSC Report concludes that the burst noise effect of AIS could affect VHF marine radio communications under certain conditions. Within the current intense electromagnetic environment present in the band, AIS signals may not significantly impact issues surrounding communications performance in the VHF maritime band.

The current state-of-the-art in digital radio communications provides mitigation techniques that would provide adequate protection against this potential AIS interference to MariTEL's proposed data service. Given the congested radio environment in the VHF band, Maritel would likely need to employ these mitigation techniques even if no AIS operations were present. Based on JSC Report and the effects of existing systems operating in this environment, it is reasonable to conclude that the current state-of-the art of signal processing in digital radio communications would provide the necessary mitigating options (including FEC, block interleaving and other packet data radio techniques), that if employed, would provide adequate protection for a digital PC service even with the introduction of AIS to the band.

For the foregoing reasons, the FCC should deny MariTEL's petition.

Sincerely,

A handwritten signature in black ink, appearing to read 'Fredrick R. Wentland', written over a horizontal line.

Fredrick R. Wentland
Associate Administrator
Office of Spectrum Management

Enclosure

cc: Edmond J. Thomas, Chief, Office of Engineering and Technology

JSC-PR-04-007

DEPARTMENT OF DEFENSE
JOINT SPECTRUM CENTER
ANNAPOLIS, MARYLAND 21402-5064

**EMC ANALYSIS OF UNIVERSAL AUTOMATIC
IDENTIFICATION AND PUBLIC CORRESPONDENCE
SYSTEMS IN THE MARITIME VHF BAND**

Prepared for

US COAST GUARD/G-SCT-2
2100 Second Street, SW
Washington, DC 20593-0002

JSC Project Engineer

Robert Lynch



FEBRUARY 2004

PROJECT REPORT

Prepared by

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Alion Science and Technology
Under Contract to
Department of Defense

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JSC-PR-04-007

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This report has been reviewed by the following Alion personnel:

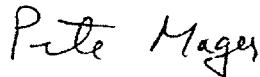


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14. ABSTRACT An electromagnetic compatibility (EMC) analysis of the potential for interference from a single automatic identification system (AIS) transmitter to a public correspondence (PC) VHF/FM receiver operating in both the voice and data modes was completed in December 2003. Subsequently, and prior to documenting the first analysis, the USCG requested an additional EMC analysis of potential interference from multiple shipborne AIS transmitters, again on a maritime PC receiver operating in the same modes. Both analyses are documented in this report. Frequency and antenna distance separations required in order to eliminate the interference were determined. To mitigate interference to the PC receiver in the data mode, the need for forward error correction code was investigated. The appropriate code values were calculated and are provided in this report.					
15. SUBJECT TERMS AIS, Achieved Performance Measure, Articulation Score, Automatic Identification System, Bit Error Rate, COSAM, Electromagnetic Compatibility, public correspondence, Ross DSC 500 Receiver, Spherical Earth Propagation Model					
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EXECUTIVE SUMMARY

The United States Coast Guard requested that the Joint Spectrum Center (JSC) perform an electromagnetic compatibility analysis of the potential for interference from an Automatic Identification System (AIS) transmitter to a Public Correspondence (PC) VHF/FM receiver (in both voice and data modes).

The effect on the performance of the maritime PC receiver in the presence of the AIS transmitter(s) was analyzed using the JSC Cosite Model (COSAM Version 5.2). The results of the analysis are as follows:

With respect to the analysis of a maritime PC receiver operating in the voice mode, some interference from the single and multiple AISs was predicted, but the analysis results indicate that this interference would not adversely affect the receiver. Interference from both single and multiple AIS transmitters to the maritime PC receiver operating in the data mode was predicted.

The frequency and antenna separations required to reduce the interference to the maritime PC receiver operating in the data mode were determined and are documented in the report. Further, the use of a Reed-Solomon forward error correction code in the maritime PC receiver could also be used to eliminate the effects of the interference. The appropriate code values were calculated and are provided in this report.

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GLOSSARY

AGC	Automatic Gain Control
AIS	Automatic Identification System
AS	Articulation Score
BER	Bit Error Rate
bps	Bits per Second
COSAM	Cosite Analysis Model
dBc	Power Level Expressed in Decibels Referenced to the Carrier Power
dBm	Power Level Expressed in Decibels Referenced to the One Milliwatt
dB _i	Antenna Gain in Decibels with Reference to an Isotropic Radiator
DSC	Digital Selective Calling
EPF	Equipment Parameter File
FEC	Forward Error Correction
FM	Frequency Modulation
GMSK	Gaussian-filtered Minimum Shift Keying
GPS	Global Positioning System
HDLC	High-Level Data Link Control
IF	Intermediate Frequency
JSC	Joint Spectrum Center
kbps	Kilobits per Second
kHz	Kilohertz
MHz	Megahertz
MMSI	Maritime Mobile Service Identity
ms	Milliseconds
PC	Public Correspondence
P_{ino}	Mean Effective On-tune Undesired Power
PRF	Pulse Repetition Frequency
RAS1	Receiver Adjacent Signal 1
RS	Reed-Solomon
SEM	Spherical Earth Model
SINAD	Signal + Noise + Distortion to Noise + Distortion Ratio
TAS	Transmitter Adjacent Signal
TDMA	Time Division Multiple Access
USCG	United States Coast Guard
VHF	Very High Frequency
WRC	World Radio Conference

SECTION 1 – INTRODUCTION

BACKGROUND

The Universal Shipborne Automatic Identification System (AIS) operates on two or more very high frequency (VHF) maritime mobile radio channels using time division multiple access (TDMA). The AIS update rate is determined by the ship speed and turn rate. The faster the ship speed and turn rate, the higher the update rate; the fastest update rate is one time every two seconds. The AIS is used to ensure safe navigation by sharing ship-to-ship position, speed, course, heading, rate of turn, ship status and voyage information, and safety-related messages. The AIS also operates in ship-to-shore and shore-to-ship modes.

After the 2000 World Radio Conference (WRC), two channels were designated for AIS operation and a footnote was added to Appendix 18 (specific footnote L) of the *ITU Radio Regulations* titled “Table of Transmitting Frequencies in the VHF Maritime Mobile Band” as follows:

These channels (AIS 1 and AIS 2) will be used for an automatic ship identification and surveillance system capable of providing worldwide operation on high seas, unless other frequencies are designated on a regional basis for this purpose.¹

The channels allocated are the AIS 1 (161.975 MHz.) and the AIS 2 (162.025 MHz). The AIS 1 falls within the nine 25 kHz duplex channels currently utilized by the VHF maritime Public Correspondence (PC) band. These PC channels are 24, 84, 25, 85, 26, 86, 27, 87, and 28. The AIS 2 is allocated in a federal government band and the AIS 1 is PC channel 87B.

Both the AIS transmitter and the PC receiver use duplex and simplex adjacent channels in the maritime mobile VHF band that can potentially result in numerous interference scenarios for communications between systems.

The United States Coast Guard (USCG) had requested that the Joint Spectrum Center (JSC) perform an electromagnetic compatibility analysis of the effects of a single AIS transmitter on the performance of a maritime PC receiver (in both the voice and data modes). This analysis was completed in December 2003. Subsequently, the USCG requested an additional analysis of the effect of multiple AIS

¹*ITU Radio Regulations*, Appendix 18 (WRC-2000), Table of Transmitting Frequencies in the VHF Maritime Mobile Band, Geneva: International Telecommunication Union, 2001

transmitters on a maritime PC receiver (in both the voice and data modes). Both analyses are documented in this report.

OBJECTIVE

The objective of this task was to determine if either single or multiple AIS transmitters (simplex mode) cause electromagnetic interference to a maritime PC receiver operating in either the data or the voice mode and if so, to determine the frequency and antenna separations that are required in order to eliminate the interference.

APPROACH

General

Since the requirements for the PC receiver are undefined, with the concurrence of the USCG, the analysis team selected the Ross DSC 500 and Neulink NL6000 as typical PC receivers. The Ross is a high-end VHF receiver that can operate in either the clear FM voice mode, or a digital data mode. For this analysis, the Ross receiver was selected for the analog voice mode. The Neulink NL6000 receiver was selected for the digital data mode. The Ross DSC 500 and the Neulink NL6000 receiver performance was evaluated in the presence of a Furuno Model FA-100 AIS transmitter, an IEC 61993-2 certified² AIS unit. Measurements were taken of the Furuno Model FA-100 AIS transmitter and the Ross DSC 500 PC receiver. Two performance measures were established for the analysis; an articulation score (AS) for voice mode and a bit error rate (BER) for data mode. The impact of the AIS emissions on the maritime PC receivers was analyzed using a computer simulation model, the JSC Cosite Analysis Model (COSAM).³

When interference is predicted for the data mode, factors like, forward error correction (FEC) will be investigated to mitigate the problem.

²IEC Standard 61993-1 Part 2: Maritime Navigation and Radiocommunication Equipment and Systems-Automatic Identification Systems (AIS)-Part 2: Class A Shipborne Equipment of the Automatic Identification System (AIS)-Operational and Performance Requirements, Methods of Testing and Required Test Results, Geneva: 17 December 2001

³Laura McIntyre and Don Wheeler, *Cosite Analysis Model Version 5.2*, JSC-UM-02-098, Annapolis, MD: DoD JSC, September 2002

Measurements

The AIS emission characteristics and the PC receiver characteristics were modeled based on measurements performed in the JSC laboratory and from data gleaned from technical manuals. The measurements conducted on the Furuno Model FA-100 AIS transmitter and the Ross DSC 500 PC VHF receiver were based on MIL-STD-449D⁴ procedures for conducted emissions spectrum characteristics (Non-Pulsed CE107), adjacent signal interference (CS114), and automatic gain control (AGC) (Impulse Response Measurement CS117). The measurement results were used to construct detailed equipment parameters records required for COSAM. A summary of technical characteristics for both the Furuno transmitter and the Ross DSC 500 receiver are shown in Appendix A, and the JSC measured data are shown in Appendix B.

Neulink NL6000 receiver measured characteristics were not available. The Neulink NL6000 receiver was modeled based on data from technical manuals and telephone conversations with the manufacturer. A summary of technical characteristics for the Furuno transmitter, the Ross DSC 500, and Neulink NL6000 receivers are shown in Appendix A. The JSC measured data are shown in Appendix B. For convenience in this report, the Furuno Model FA-100 AIS transmitter will be referred to as the AIS transmitter. The Ross DSC 500 and the Neulink NL6000 PC VHF receivers will be referred to as PC analog and PC digital, respectively.

Modeling

COSAM is a statistical model used to account for uncertainties in equipment characteristics and coupling losses in the calculation of signal power levels. The statistical distributions of the background noise power levels and the desired power levels are calculated at a PC receiver input. Samples from these distributions are selected randomly during a computer simulation to generate receiver performance distributions of the AS for analog voice or of the BER for digital receivers. The AS and BER values used in the analysis are the 95 percentile point in the predicted AS and BER distribution.

⁴*Military Standard, Radio Frequency Spectrum Characteristics, Measurements of*, MIL-STD-449D, Washington DC: US Department of Defense; 22 February 1973 (with Notice 1, 18 May 1976)

Articulation Score

An AS, used as a measure of performance for analog voice receivers, is derived from the percent of monosyllabic spoken words correctly understood by a human listener panel. An AS prediction model is incorporated in COSAM to simulate a trained listener panel.^{5,6} The AS output derived from COSAM can be interpreted as a probability that a given word is not received in error.

A human-error correction process occurs when a person listens to an analog voice signal. Each spoken word is a string of phonemes. A monosyllabic word typically contains three phonemes. The listener must correctly identify each of those phonemes to correctly identify the word. Each phoneme can be regarded as a string of 10-ms phoneme fragments, referred to as elements. Related studies indicate that the listener can correctly identify a word (or phoneme) even when many elements within the word are unrecognizable due to interference. Normal connected speech can be understood even if some of the syllables are unintelligible because the listener can deduce the meaning from the context of the sentence. Even under near perfect conditions, due to unavoidable errors, the maximum AS normally attainable is about 95 percent. Based on a previous analysis of similar receivers, an AS of 95 percent was determined to be an acceptable baseline performance threshold for the PC receiver.⁷ An AS of 80 percent enables the listener to understand every sentence without significant effort. When the AS degrades to near 70 percent, the listener must concentrate to understand what is said and below 60 percent, the intelligibility is quite poor.⁸

Bit Error Rate

The BER is the ratio of the number of bits of a digital message incorrectly received due to interference, receiver noise, or ambient noise to the number of bits in the message transmitted. A BER of 1×10^{-6} was determined to be an acceptable baseline performance threshold for the PC receiver.

This threshold is based on a benign environment where there is no Rayleigh fading, no multipath, no external interference, and without any FEC.

⁵T. Reilly, L. McIntyre, and M. Maiuzzo, "Models of Speech Intelligibility for Channels Subject to Intermittent Interference," IEEE Military Communications Conference, Washington, DC: 19-22 October 1987

⁶Miller, George, and Licklider, "The Intelligibility of Interrupted Speech," Psycho-Acoustic Laboratory, Harvard University, Cambridge MA: October 22, 1949

⁷Kenneth Roberts and Howard McDonald, Analysis of the UHF Surrogate Satellite Relay (USSR), ECAC-CR-93-020, DoD ECAC (now JSC), Annapolis, MD: October 1976

⁸Dr. Andrew Marsh, "Speech Intelligibility," Architectural Science Laboratory, University of Western Australia: 1999

Analysis Procedures

As a first step to identifying possible interference caused by a single shipborne AIS transmitter to a PC receiver operating in the VHF/FM voice mode, an AS threshold was determined in the presence of receiver and ambient noise, with the AIS transmitter disabled. The receiver and ambient noise level was used to determine the minimum acceptable desired signal. The sum of Galactic and background environmental noise under quiet conditions was assumed to be ambient noise.

The USCG identified four shipborne AIS transmitter environments that represent typical vessel traffic environments, with varying update rates, off the coast of Ft. Lauderdale, Florida.⁹ For the analysis of the effect of multiple AIS transmitters on a maritime PC receiver, the densest environment was selected. The update rates of the AIS transmissions were determined by the speed of the ships but did not include any change in the update rate that would be caused by ship course changes since course change data were not available.

The project team repeated the analysis with the AIS transmitters in this environment turned on, and compared the PC receiver performance with the baseline case.

A breakdown of the procedures is provided below:

The baseline AS and BER values resulting from these conditions represent ideal receiver performance expected in a quiet environment with no interference present and minimum desired signal. In actual operation, the PC receiver would typically operate with higher noise levels due to man-made noise from ship systems, etc., resulting in higher desired signal levels.

Next, the AIS transmitter was enabled and tuned to channel AIS 1 (161.975 MHz). The PC receiver AS and BER performance was determined at frequencies that were off tuned by increments of 25, 50, and 75 kHz from the AIS transmitter, with horizontal antenna separations of 10, 1,000, and 10,000 feet. The AS was also determined for frequency separations of 25 and 75 kHz for a co-ship environment with a

⁹David Pietraszewski, USCG R&D Center, email to JSC/J8, Subject: *Screens of AIS traffic off coast of Ft. Lauderdale, FL*, Washington, DC: 11 December 2003

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vertical separation of 60 feet. The effect of AIS interference to the PC receiver performance was determined by comparing the AS and BER baselines to the AS and BER performance with the AIS transmitter operating. In addition, with the PC receiver tuned to the edge of its tuning band (156.025 MHz), the project team determined the horizontal antenna separation required to achieve the original baseline AS and BER.

SECTION 2 – ANALYSIS

MODELING

The AIS transmitter was turned off to establish a baseline receiver performance threshold in the presence of receiver and ambient noise. Based on a previous analysis of similar receivers, a baseline AS of 95 percent and BER of 1×10^{-6} were determined to be appropriate baseline performance thresholds. The desired signal was adjusted to a level that yielded a signal-to-noise ratio that ensured acceptable receiver performance for the PC receiver in the analog voice mode. The desired signal level of the PC receiver operating in the data mode was adjusted to a level of -98 dBm based on FCC Standards¹⁰ and based on previous JSC analyses.

Next, the AIS transmitter was activated. The mean effective on-tune undesired power (P_{ino}) at the PC receiver input was calculated using the AIS peak transmit power, antenna gains, system losses, the frequency-dependent rejection factor associated with the interference mechanism being evaluated, and a propagation loss based on antenna separation. The mean P_{ino} power levels and the above associated parameters are shown in Appendixes D and E. The effect of intermodulation interference on the PC receiver performance was not considered due to the low duty cycle of the AIS transmitter. Two interference mechanisms were evaluated; transmitter broadband noise and adjacent-signal interference. The AIS TDMA emission appears as undesired pulses to the PC receiver. Depending on the pulse power and duration, pulse-stretching effects from the undesired AIS transmissions may remain for some time after the pulse has disappeared. Pulse stretching effects are generally the result of ringing in the PC receiver filters or AGC capture. In addition to pulse-stretching effects, high-power effects such as desensitization were considered. Based on the measurements taken, the noise-power levels emitted between pulses (information bursts) by the AIS power amplifier were determined to be insignificant and therefore were not considered in this analysis.

Once the desired-to-undesired power ratio was computed at the PC receiver input, COSAM was used to determine the PC receiver performance, using the appropriate degradation curve. If the AS was less than the specified receiver performance threshold, the frequency separation and/or antenna separation was increased until the required receiver output response was achieved. PC receiver performance degradation caused by the worst-case AIS transmission duty cycle of one pulse every two seconds was analyzed with the antennas separated horizontally and then vertically. The worst-case pulse repetition frequency (PRF) was used for vessels exceeding 23 knots or 14 knots and turning. A typical antenna

¹⁰47 CFR, Chapter 1-Federal Communications Commission, Part 80 – Stations in the Maritime Services, Section 80.753-Signal Strength Requirements at the Service Area Contour, Washington, DC: October 1, 1997

designed for a maritime environment is a CELWAVE coaxial antenna. A VHF antenna with characteristics similar to the CELWAVE antenna was used in the analysis.

The AIS transmitter was tuned to the AIS 1 (161.975 MHz) channel. The performance of a PC receiver operating in both the voice and data modes was determined at frequencies that were off tuned from the AIS transmitter by increments of 25, 50, and 75 kHz, with horizontal antenna separations of 10, 1,000, and 10,000 feet for each increment. The AS was also determined for frequency separations of 25 and 75 kHz, with a vertical antenna separation of 60 feet (Note: There were no significant differences noted between the 50 and 75 kHz separations). The BER was also determined for frequency separations of 25, 50, and 75 kHz, with vertical separations of 60 feet for the antennas to model the co-ship environment. In addition, for the data mode, a 150 feet antenna separation was investigated to determine if additional antenna spacing would eliminate interference for coastal stations.

For multiple AIS transmitter effects, a worst-case vessel traffic pattern was selected from four “screen grabs” of vessel traffic off the coast of Florida, provided by the USCG (Reference 9). The worst-case traffic pattern consisted of 18 vessels, of which 11 were stationary and 7 were in motion off the coast of Fort Lauderdale, Florida. The performance of the PC receiver was analyzed at frequencies off tuned from the AIS transmitter tuned frequency by increments of 25, 50, and 75 kHz.

Single AIS Transmitter – Interference to the PC Receiver

VHF/FM Voice Mode

With the AIS transmitter disabled and the PC receiver in the voice mode, the minimum desired signal level was increased to a sensitivity level that produced an AS close to the targeted 95 percent. An AS of 95.3 percent was predicted based on a desired signal of -115 dBm. The receiver and ambient noise levels were determined to be -130.2 and -132.9 dBm, respectively.

When the AIS transmitter was enabled, the PC receiver AS was minimally degraded. Table 2-1 shows the AS for frequency increments of 25, 50, and 75 kHz, with horizontal antenna separations of 10, 1,000, and 10,000 feet for each increment.

The effects of the AIS transmission on the PC voice receiver can be completely eliminated by off-tuning the receiver to 25 kHz and separating the antennas by 10,000 feet (1.9 miles) or by off-tuning the receiver to 75 kHz and separating the antennas by 1.4 miles. This is apparently due to the AIS fundamental being received by receiver skirts.

Table 2-1. AS for Selected Frequency and Horizontal Antenna Separations

Frequency Separation (kHz)	Horizontal Antenna Separation (feet)	AS without AIS (percent)	AS with AIS (percent)
25	10	95.3	93.1
25	1,000	95.3	93.2
25	10,000	95.3	95.1
50	10	95.3	93.1
50	1,000	95.3	93.4
50	10,000	95.3	95.1
75	10	95.3	93.1
75	1,000	95.3	93.5
75	10,000	95.3	95.1

Degradation to the PC receiver from the AIS transmissions may be mitigated by off-tuning the PC receiver to the edge of its tuning band (156.025 MHz) and separating the antennas horizontally by 500 feet (0.095 miles) to obtain an AS of 95.3 percent.

With the PC receiver and AIS antennas separated vertically by 60 feet and with a desired received signal level of -115 dBm, the resulting AS was predicted to be 95.3 percent, without the AIS emissions. When the AIS transmitter is operating, degradation of the performance of the PC receiver is minimal as shown in Table 2-2. For this case, with an antenna separation of 60 feet and 25 kHz frequency separation, the AIS undesired signal power produced a mean effective on-tune AIS peak power level at the PC receiver input of -87.6 dBm with an antenna to antenna coupling loss of 70.6 dB. The antenna gains used were 2.1 dBi with 1 dB combined system losses and 61.2 dB of frequency dependent rejection.

Table 2-2. AS for Selected Frequency and Vertical Antenna Separations

Frequency Separation (kHz)	Vertical Antenna Separation (feet)	AS without AIS	AS with AIS
25	60	95.3	93.3
75	60	95.3	93.8

Data Mode

With the AIS transmitter disabled and the PC receiver in the data mode, the desired signal level of -98 dBm resulted in a BER less than, or equal to, the threshold 1×10^{-6} .

Table 2-3 shows the results for frequency increments of 25, 50, and 75 kHz, with antenna separations of 10, 1,000, and 10,000 feet for each increment.

Table 2-3. BER for Selected Frequency and Horizontal Antenna Separations

Frequency Separation (kHz)	Horizontal Antenna Separation (feet)	BER without AIS	BER with AIS
25	10	$<1 \times 10^{-6}$	3.1×10^{-2}
25	1,000	$<1 \times 10^{-6}$	2.8×10^{-2}
25	10,000	$<1 \times 10^{-6}$	7.4×10^{-5}
50	10	$<1 \times 10^{-6}$	3.1×10^{-2}
50	1,000	$<1 \times 10^{-6}$	1.4×10^{-2}
50	10,000	$<1 \times 10^{-6}$	$<1.0 \times 10^{-6}$
75	10	$<1 \times 10^{-6}$	3.1×10^{-2}
75	1,000	$<1 \times 10^{-6}$	1.2×10^{-2}
75	10,000	$<1 \times 10^{-6}$	$<1.0 \times 10^{-6}$

The effects of AIS pulsed transmissions on the PC digital receiver can be mitigated (producing a BER of 1×10^{-6}) by off-tuning the PC receiver to

- 25 kHz and separating the antennas horizontally by 2.6 miles
- 50 kHz and separating the antennas horizontally by 1.14 miles
- 75 kHz and separating the antennas horizontally by 1.04 miles
- 156.025 MHz, the edge of its tuning band, and separating the antennas by 2,000 feet (0.37 miles).

If a BER of 1×10^{-4} was acceptable, the effects of the AIS pulsed transmissions on the PC digital receiver can be mitigated by off-tuning the PC receiver to

- 25 kHz and separating the antennas horizontally by 1.8 miles
- 50 kHz and separating the antennas horizontally by 0.81 miles
- 75 kHz and separating the antennas horizontally by 0.76 miles
- 156.025 MHz, the edge of its tuning band, and separating the antennas by 900 feet (0.17 miles).

The PC receiver BER operating without the AIS emissions, was predicted to be less than 1×10^{-6} . With the AIS transmitter operating and the AIS antennas separated vertically by 60 and 150 feet, the performance of the PC receiver was degraded as shown in Table 2-4. For this case, with an antenna

separation of 60 feet and 25 kHz frequency separation, the AIS undesired signal power produced a mean effective on-tune AIS peak power level at the PC receiver input of -97.5 dBm with an antenna to antenna coupling loss of 71.7 dB. The antenna gains used were 2.1 dBi with 1 dB combined system losses and 70 dB of frequency dependent rejection.

Table 2-4. BER for Selected Frequency and Vertical Antenna Separations

Frequency Separation (kHz)	Vertical Antenna Separation (feet)	BER without AIS	BER with AIS
25	60	$<1 \times 10^{-6}$	2×10^{-2}
50	60	$<1 \times 10^{-6}$	5.6×10^{-3}
75	60	$<1 \times 10^{-6}$	4.2×10^{-3}
25	150	$<1 \times 10^{-6}$	2.7×10^{-3}
50	150	$<1 \times 10^{-6}$	7.3×10^{-5}
75	150	$<1 \times 10^{-6}$	3.8×10^{-5}

Multiple AIS Transmitters – Interference to the PC Receiver

Voice Mode

The effect of multiple maritime AIS transmitters on the performance of the PC receiver operating in voice mode was investigated. The USCG (Reference 9) provided four “screen grabs” that depict vessel traffic off the coast of Fort Lauderdale, Florida. Figure 2-1 depicts the scenario with the most congested vessel traffic and highest AIS update rates. This scenario was selected as the worst-case. Note, this analysis assumed that there is not an AIS on the victim ship.

The locations of selected vessels within a 10 mile radius of an origin located at the approximate center of the selected vessels were determined using Figure 2-1. The selected vessels are designated by the small solid circles. The location of each vessel was entered in COSAM to compute the separation distance between the AIS transmitter antennas and the PC receiver antenna located at the center of the coordinate system. The vessel number, name, x and y locations relative to the center of the coordinate system, and the AIS transmitter update rates are shown in Table 2-5. The update rate indicates how often the AIS pulse is transmitted.

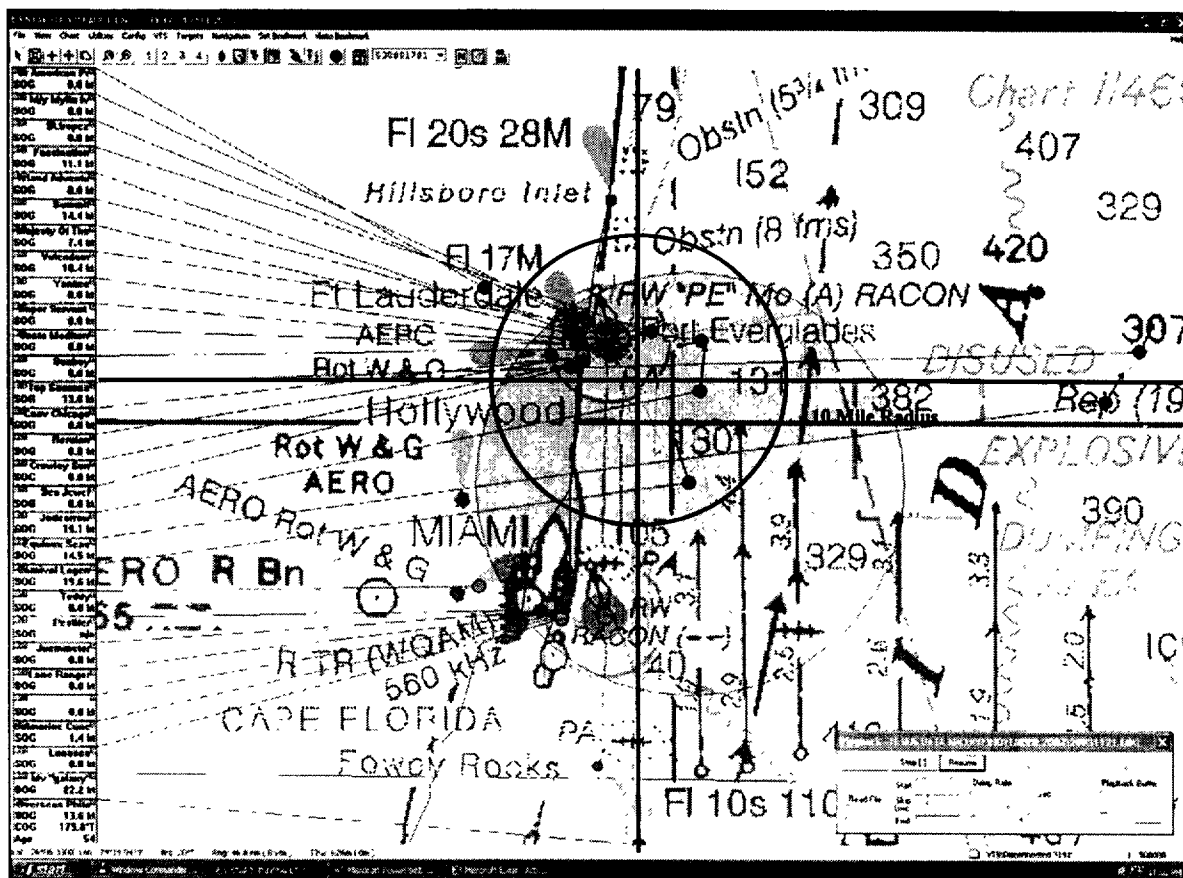


Figure 2-1. Fort Lauderdale, Florida - Worst-Case AIS Traffic Scenario

Table 2-5. Multiple AIS Transmitter Environment

Vessel Number	Vessel Name	X-Axis (miles)	Y-Axis (miles)	Update Rate (seconds)
1	Jade Arrow	4.14	0.52	6
2	Volendam	4.14	3.10	10
3	Fascination	0.52	3.62	10
4	Carnival Legend	3.62	-7.24	6
5	Sea Jewel	-5.00	.78	10
6	Crowley Sun	-4.14	1.29	10
7	Berulan	-4.14	1.81	10
8	Summit	-1.29	3.10	3.33
9	Saint Tropez	-2.59	3.62	10
10	M/y Mylin IV	-3.88	4.14	10
11	Island Adventurer	-3.62	3.10	10
12	Majesty of the Sea	-4.40	3.36	10
13	Yankee	-4.91	3.10	10
14	Super Servant	-4.91	2.59	10
15	Costa Mediterr	-4.66	2.59	10
16	Sunbay	-4.40	2.33	10
17	Top Success	4.91	0.52	10
18	Csav Chicago	-4.14	1.55	10

The results of multiple AIS transmitter emissions on the performance of the PC receiver in the voice mode are shown in Table 2-6. The degradation to the PC receiver is minimal.

Table 2-6. AS for Multiple AIS Transmitter Emissions

Frequency Separation (kHz)	AS without AIS	AS with AIS
25	95.4	94.0
50	95.4	94.9
75	95.4	95.2

Data Mode

Using the same scenario as above, the effect of multiple AIS transmitters on the performance of the PC receiver in the data mode was investigated. The AIS transmitter environment and update rates are provided in Table 2-5. BER degradation is predicted for only the 25-kHz case for the PC data mode

analysis shown in Table 2-7. This degradation is based on no Rayleigh fading or multipath of the desired signal, and in the absence of FEC and external interference other than the AIS emissions.

Table 2-7. BER for Worst-Case AIS Transmitter Emissions

Frequency Separation (kHz)	BER without AIS	BER with AIS
25	$<1 \times 10^{-6}$	1.2×10^{-5}
50	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$
75	$<1 \times 10^{-6}$	$<1 \times 10^{-6}$

FORWARD ERROR CORRECTION

Systems can facilitate digital communications on channels that would otherwise be unusable through the use of FEC. FEC can be designed to combat fading, multipath, and noise-like pulsed interference. FEC is available on new systems and as a retrofit to older systems. Since the AIS transmitter transmits TDMA pulses, an FEC scheme conducive to correcting the effect of pulsed interference on the PC receiver performance could be applied. Reed-Solomon (RS) code with an interleaver is an effective FEC scheme to mitigate the effect of pulsed interference.

The COSAM analysis was repeated with FEC applied. This analysis showed that the PC digital receiver desired BER performance of 1×10^{-6} could be achieved in the presence of a single AIS transmitter by implementing a (31, 19) RS FEC code, interleave depth of 16 with a minimal antenna separation of 10 feet and a frequency separation of 25 kHz.

Applying the same RS code and parameters to the PC receiver in the multiple AIS transmitter environment shown in Figure 2-1 mitigates the effects of AIS pulses on the PC receiver performance with a delay time of 0.112 seconds. This code works with the PC receiver information data rate of 13,515 bits per second (bps). By implementing this FEC code, the data rate must be increased to 22,050 bps ($13515 \times [31/19]$). This FEC technique is one possible way to mitigate the effect of multiple AISs and other FEC techniques may work as well.